MR No. E6C25

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED

May 1946 as
Memorandum Report E6C25

HYDRAULIC CHARACTERISTICS OF THE NACA INJECTION IMPELLER

By William K. Ritter, Irving A. Johnsen, and Seymour Lieblein

Aircraft Engine Research Laboratory
Cleveland, Ohio

NACA

WASHINGTON

E-278

NACA AIRCRAFT ENGINE RESEARCH LABORATORY

MEMORANDUM REPORT

for the

Air Technical Service Command, Army Air Forces

HYDRAULIC CHARACTERISTICS OF THE NACA INJECTION IMPELLER

By William K. Ritter, Irving A. Johnsen, and Seymour Lieblein

SUMMARY

A mock-up injection impeller was designed and tested to investigate the hydraulic characteristics and limitations of the NACA injection impeller designed for an 18-cylinder double-row radial air-cooled engine having a normal rating of 2000 brake horsepower at 2400 rpm. In addition to determining the form and magnitude of the critical factors of fuel-transfer leakage and peripheral fuel distribution in the original unit designed for the engine, an investigation was made of the effects of design variations in the component parts of the system on these hydraulic characteristics. Peripheral distribution, as indicated by the method of collection, was satisfactory in the original design over the entire range of engine operation. Transfer-leakage characteristics were also satisfactory but were found in subsequent test units to be sensitive to certain design changes. Results of these expanded tests led to the establishment of some basic design criterions and limitations for this type of fuel injection system. From these design principles, several revisions in the nozzle ring, the collector cup, and the impeller fuel-distribution annulus of the original-design unit were made to improve the fuel-transfer, fuel-pumping, and fuel-equalizing characteristics of the unit.

INTRODUCTION

At the request of the Air Technical Service Command, Army Air Forces, a general investigation of means to improve the cooling of an 18-cylinder double-row radial air-cooled engine is being conducted at the NACA Cleveland laboratory. The NACA injection impeller, developed as part of this investigation (see reference 1), was designed and first used to improve the cooling of the engine by improving the fuel-air mixture distribution. This injection-impeller design, through a suitable transfer system, introduces the fuel under the action of centrifugal force into the discharge portions of the impeller air passages. The fuel is thus discharged into the air-flow system in a region of high temperature and velocity.

The effectiveness of the NACA injection impeller in reducing maximum cylinder-head temperatures depends upon the degree of uniformity of the resulting cylinder fuel-air mixtures. This variation in fuel-air mixture is a function of the uniformity of both the air distribution in the intake system and the fuel distribution as established by impeller injection. Because these factors were not separately defined in the original tests, a program was set up to investigate the factor of fuel distribution established by the hydraulic system of the NACA injection impeller.

Injection-impeller fuel distribution is principally affected by transfer-leakage form and magnitude and peripheral discharge symmetry. These hydraulic characteristics were determined for the original NACA injection impeller designed for the double-row radial engine and the effects of alterations of the component parts of the unit were investigated. From the results of this investigation, design criterions and limiting conditions for the hydraulic system can be established. In addition to their use in providing the basis for substantial improvements in the hydraulic characteristics of the NACA injection impeller for the engine, these criterions and limitations can be employed in the construction of this type of injection impeller for use in any aircraft engine having cooling of other difficulties that arise from a nonuniform fuel distribution.

APPARATUS

In order to facilitate the investigation of the hydraulics of the NACA injection impeller, a mock-up containing the complete fuel-passage system but without the air passages of the bladed impeller was constructed. The use of the mock-up injection impeller made possible a simple test installation and provided greater flexibility for design changes in both the impeller and fuel-transfer sections than would have been possible with the bladed impeller. Sectional views of the NACA injection-impeller installation for the R-3350 engine and the hydraulic mock-up installation for this impeller are shown for comparison in figure 1. The outer diameter of the mock-up impeller is equal to the diameter at the point of discharge of the fuel into the air streams of the bladed impeller.

Because leakage between the stationary nozzle ring and the rotating collector cup (fig. 1) was expected, the mock-up impeller test rig was so designed that this fuel-transfer leakage upstream of the impeller could be satisfactorily collected and measured. In an actual engine installation, any fuel leaking from the transfer section would be thrown out in a spray similar to that from a slinger ring and would thus be drawn into the impeller with the entering air. Although the effects of impeller air flow and of discharge-stream impingement against the impeller blades could not be defined in the mock-up tests, it is expected that the presence of impeller blading and channel air flow has no appreciable effect on impeller fuel distribution.

An alternate design involving the introduction of fuel directly into the impeller fuel-distribution annulus from the rear or web section of the impeller was also constructed and is shown in figure 2. This direct-flow unit, which eliminated the functional necessity of the vaned collector cup and the fuel-transfer passages through the body of the impeller, had a stationary nozzle ring concentrically mounted around the impeller shaft end to transfer the fluid symmetrically into the impeller annulus. The nozzle-ring tubing, shown in the figure in a vertical plane, was installed in a horizontal position in the installations for both the direct-flow (fig. 2) and original (fig. 1(b)) mock-up units.

TEST SETUP

Injection-impeller installation. - The mock-up impeller was tested in a test installation that incorporated an electric driving dynamometer and step-up gear box. In the interests of safety, water was used for the mock-up tests instead of gasoline and a density correction was applied to weight-flow data. The quantity of water metered to the external tubing connections of the nozzle ring was controlled by conventional valves and the water-flow regulation was therefore independent of the impeller speed. A rotameter measured the weight flow of water delivered.

Transfer-leakage collector. - The fluid transfer leakage was collected in a drum-type chamber bolted to the gear box head and concentrically mounted around the collector-cup nozzle-ring section (fig. 1(b)). A seal ring located on the collector cup prevented any passage of liquid from the impeller-discharge-distribution collector into the leakage collector. The transfer-leakage collector was fitted with a breather vent, a drain tube, and two transparent plastic side windows. These windows permitted visual observation of the form and magnitude of the transfer-leakage spray sheet and, in addition, provided access for assembly-clearance measurements.

Discharge-distribution collector. - The collector for determining impeller-discharge distribution (fig. 1(b)) is a cylindrical drum divided into five equal chambers, numbered from 1 to 5 in the direction of impeller rotation beginning at the bottom. Because of the difficulties involved in drainage and inter-chamber leakage through the receiving annulus, it is not feasible to divide the collector into more than five chambers.

The water leaving the impeller periphery is discharged into the chambers through a receiving annulus consisting of two radially converging lips welded to the inner sides of the chamber partitions. The receiving annulus extends circumferentially around the mock-up impeller directly in line with the discharge streams. The outer or converged opening of the receiving annulus is slightly wider than the estimated thickness of the water jets in order to induce a high velocity air flow with the emitting streams. This air swirl due to impeller rotation reduces the tendency of the liquid to drip back through the annulus opening. A drain is provided for any water or spray that might drip down the annulus lips or into the central section of the collector.

Each chamber is fitted with an air vent and with drain tubes, which lead to a collecting tank stand. This tank stand is constructed to permit the taking of simultaneous collection readings for each of the five chambers. On the basis of an inspection of collector operation and chamber-partition construction and spacing, it is estimated that the accuracy of chamber deviation readings is approximately 1 percent.

Discharge collector for direct-flow-impeller installation. - An alternate drum-type discharge collector with a face plate containing the mounting supports for the nozzle-ring section and the enclosing leakage collector was used for the tests of the direct-flow unit (fig. 2). Accessory parts are installed on the impeller rear face to deflect the flow into the impeller fuel-distribution annulus and to sling the transfer leakage into the collector.

The face-plate assembly of the collector can be replaced by a transparent plastic window in order to provide visual observation of the impeller discharge of the original design units. Further inspection of the nature of the discharge streams by photographic and stroboscopic examination is thus permitted.

Measurements. - The symmetry of the peripheral distribution was recorded as the percentage deviation of each chamber from the average flow collected in the five chambers. The rate of flow into each chamber or section of the collector was calculated from individual bucket weights taken simultaneously over a suitable length of time. All data are expressed as a gasoline-weight flow equivalent to the volume of the measured weight of water.

Dynamometer speed, as measured by an electrically actuated revolution counter and a stop watch, was adjusted to maintain impeller speeds equivalent to those corresponding to engine operating speeds. Impeller operation is therefore expressed in terms of engine speed and gasoline flow.

Nozzle-ring water pressure was measured by a static-pressure tap at the bottom of the ring connected to water or mercury manometers.

TESTS

Fuel-flow test points over the established range of engine operation used in the mock-up tests were based on engine manufacturer's data and were taken to include the rated operation points run for the tests of the double-row radial engine using the NACA injection impeller. Mock-up fuel-flow values at engine speeds of 2600 and 2800 rpm were increased to include approximately 40 and 60 percent water injection, respectively. The normal range of engine operation was established in the mock-up tests as the test fuel-flow points corresponding to engine speeds from 2000 to 2800 rpm.

Distribution tests included one run of test fuel flows at eight engine speeds from 600 to 2800 rpm and four runs over a full fuel-flow range at constant engine speeds of 2000, 2200, 2400, and 2800 rpm. Many of the fuel-flow test points were included in each constant speed run, thus providing additional data for constant fuel-flow analysis.

Transfer-leakage tests were run at equivalent gasoline flow rates of 50 to 3200 pounds per hour at engine speeds of 1400, 2000, 2400, and 2800 rpm. Leakage data were also obtained from distribution tests.

In order to obtain visual observation of the flow patterns of the discharge streams leaving the nozzle ring, stationary bench-flow tests over the full range of fuel flow were conducted on the several nozzle rings. An indication of the transfer-leakage and flow-symmetry characteristics of a nozzle ring was thus obtained.

Other special investigations included visual pattern tests obtained by passing a fluid dye through the hydraulic system, accuracy tests on the installation itself to determine the effect of alterations in the test setup, and a leakage and distribution run at an engine speed of 200 rpm to determine injection-impeller performance at engine starting conditions.

HYDRAULIC CHARACTERISTICS OF NACA INJECTION IMPELLER FOR DOUBLE-ROW RADIAL ENGINE

Flow capacity and leakage. - The transfer leakage (fig. 3) between the nozzle ring and the collector cup (fuel-transfer unit) in the NACA injection impeller for the double-row radial engine was relatively high at low flows, gradually decreased to a minimum value, and increased again at high flows. An increase in engine speed decreased the leakage at both high and low flows and increased the range of minimum leakage. In general, the transfer-leakage characteristics of the original design were satisfactory for use in conjunction with the engine, with leakage of less than 5 percent over the normal engine operating range. Leakages are given as percentages of total flow.

Visual inspection of the operation of the mock-up unit showed that, in the normal range of engine operation, the small amount of leakage was in the form of a fine peripheral sheet. In an engine therefore this leakage would be readily atomized and distributed with a reasonable degree of uniformity into the impeller entrance.

Pheripheral distribution of fuel. - Peripheral fuel distribution for the NACA injection impeller was satisfactory in the mock-up impeller tests for use in conjunction with the engine. The variation in the fuel discharge for the established test range of engine operation is shown in figure 4(a); figures 4(b) and (c) show results of typical constant-speed and constant-flow runs. The values of maximum deviation from symmetrical distribution found in these tests of the original impeller are listed in the following table:

MAXIMUM PERCENTAGE DEVIATION FROM AVERAGE FUEL-DISCHARGE

DISTRIBUTION IN ORIGINAL NACA INJECTION IMPELLER

FOR DOUBLE-ROW RADIAL ENGINE

Engine speed (rpm) \ Fuel flow (lb/hr)	300	433	575	925	1510	2032	2600	3198
200	9.31							
1400	9.47							
2000	9.78	7.25	3.79	2.72	3.04			
2200		9.56	5.97	2.29	4.04	3.71		
2400			6.88	6.08	3.25	3.69	3.03	
2800				5.49	6.13	3.93	2.21	3.00

From an inspection of the constant-speed results, it can be seen that the distribution symmetry improves with increasing rates of flow, with the trend especially noticeable at very low flow rates. Constant-fuel flow data show a slight tendency for the distribution to become poorer with increasing engine speeds.

Starting conditions. - The mock-up injection-impeller unit, when tested at starting conditions of an engine speed of 200 rpm and at a fuel flow of 300 pounds per hour, showed that the maximum variation from average distribution was approximately 10 percent and leakage approximately 15 percent. It is expected that no starting difficulties should result from the use of a fuel-injection impeller of this type.

PERFORMANCE EFFECT OF DESIGN CHANGES

General leakage characteristics. - In all injection-impeller tests, the variation in fuel-transfer leakage followed the general trend shown in the curves of figure 3. The magnitude of the leakage at low fuel flows was, to a large extent, a function of the nozzle-ring design. In bench-flow tests of this original nozzle ring, all the fluid emitting from the holes did not flow clear of the nozzle-ring face in the form of jets until a substantial flow was reached (approximately 900 lb/hr). At flows less than 900 pounds per hour, much of the fluid dripped directly down the face of the ring and leaked out through the clearance between the nozzle ring and the collector cup. The drip was a result of insufficient flow, gravitation, and local flow concentration in the region of the inlet-tubing connections.

The critical fuel-flow rate of about 900 pounds per hour, as determined from bench-flow tests, generally marked the transition to the minimum-leakage range (fig. 3). In this minimum-leakage portion of the flow range, nozzle-ring jet velocity was sufficient to prevent direct dripping down the ring face and the leakage was primarily a result of jet divergence, gravitation, and entrance splashing.

The increased leakage at high flows was due to the inability of the collector cup and fuel-induction vanes to pump the larger amounts of fuel without overloading the cup. Insufficient rotation was imparted to the fuel by the fuel-induction vanes; thus, fuel rotation at the entrance to the collector-cup discharge holes was not equal to cup rotation. This slip, in addition to a small change in axial-flow velocity through the cup, hydraulically limited the quantity of fuel that could be delivered by the cup for a given rotational speed. Another factor determining flow capacity was the air flow through the impeller passages. Because the fuel flow did not completely fill the passages, air was pumped through the hydraulic system from the collector cup-nozzle ring-clearance space, thus causing a pressure differential or suction across the clearance space and through the collector cup. The air flow thus induced increased the fuel discharge from the collector cup and was also effective in reducing fuel-transfer losses across the clearance gap. The resultant of the induced air flow and the fluid-rotation effects determined the capacity of the collector cup before overflow and leakage occurred.

Because fluid rotation and air-suction effect are functions of rotational speed, leakage rates were lower for high engine speeds than for low engine speeds (fig. 3). A restriction of the impeller-passage air flow, as shown in the mock-up tests, increased leakage at high fuel flows.

Collector-cup and nozzle-ring design. - Tests of various modifications of the original injection-impeller unit indicated that leakage characteristics, particularly at high fuel flows, can be substantially improved by providing greater pumping action in the collector cup. A cup of revised design incorporating greater pumping action resulted in the total elimination of the increasing leakage tendencies at high flows, as shown in figure 5. These curves, based on the original impeller for the double-row radial engine, show leakage values less than 5 percent over the entire speed range at fuel flows from 600 to 3200 pounds per hour and values of about 1 percent at the higher flow rates. This high-flow characteristic is very desirable for the development of large power outputs, especially when water injection is incorporated.

The principal design feature of this improved cup was the increase in the number of fuel-induction spacer vanes from 11 to 16 and the increase in radial height of the vanes to extend completely across the passage. The marked effect of the increased pumping action provided by the full vanes was clearly demonstrated by a test of the revised collector cup in which the complete removal of the fuel-induction vanes resulted in the reappearance of the large increase in leakage at high fuel flows and a leakage similar to that for the original collector cup.

Another design feature of the revised cup included a maximum increase in raduis through the cup with a rapid increase in radius at the entrance, thus providing a maximum axial centrifugal-force component. When the nozzle ring was redesigned to incorporate slotted discharge orifices at a minimum radius, a correspondingly small cup entrance area at minimum radius was obtained. This area reduction resulted in a high velocity air inflow with the entering jets at the collector-cup entrance.

Analysis of performance results also indicated that improved leakage characteristics in the low-flow and minimum-leakage range could be obtained by restricting the nozzle-ring discharge area and thereby increasing the discharge-jet velocity. A nozzle ring with slotted discharge orifices of a total area equal to approximately one-fourth that of the unit originally designed for the engine was tested in conjunction with the original-design collector cup and impeller. The unit incorporating this nozzle ring had excellent leakage characteristics, reducing the minimum leakage from a value of 2 percent to less than 0.5 percent and maintaining a leakage of less than 1 percent in the normal fuel-flow range from 1000 to 2000 pounds per hour. The increase in nozzle-discharge-jet velocity was not effective in reducing leakage in the high-flow range. At an equivalent fuel flow of 2000 pounds per hour, the pressure drop across the nozzle-ring discharge orifices rose to 48 inches of mercury as compared with 4.1 inches of mercury required by the original nozzle ring for the engine. The use of a reduced-area ring, because of its excessive pressure requirements, might necessitate carburetor and fuel-pump adjustments.

Another method of improving low-flow leakage characteristics incorporated a circumferential lip at the outer radius of the nozzle-ring slots, which extended axially into the collector-cup-entrance annulus. The prevention of the direct leakage of fluid through the clearance space by this method of collector-cup nozzle-ring overlap had a marked effect on low-flow leakage values up to 1000 pounds per hour. A slotted nozzle ring with a lip, tested with the original impeller and collector cup, considerably reduced the low-flow leakage found for this same installation without the lip. In these tests, the lip feature had no effect on high-flow leakage tendencies. A unit combining both a method of overlap and the entrance features of the revised collector cup, however, could not be developed because of the space limitations of the injection-impeller installation in the engine.

Nozzle-ring pressure. - Correlation of the mock-up injection-impeller tests and bench-flow tests of the nozzle ring showed that nozzle-ring pressure requirements could be determined from static tests; that is, the centrifugal action of the impeller and the variation in clearance air flow did not measurably affect the pressure drop across the nozzle-ring discharge orifice. The effect of the form of discharge orifice was also negligible, as two similar nozzle rings with equal discharge areas, one with circular holes and the other with rectangular slots, had nearly the same pressure requirements. For the scope and conditions of the tests fuel metering was therefore a function of orifice area and discharge head. Results of the pressure investigation showed that the pressure drop of the nozzle ring designed for the engine was in the allowable range for satisfactory fuel metering without extensive alterations to standard carburetors.

Impeller fuel-transfer passages. - The inclined fuel-transfer passages of the impeller act as a centrifugal pump in transferring the fuel flow from the collector cup to the distribution annulus. Results of tests and analyses indicated that a maximum increase in radius and an adequate transfer passage area are desirable. A reduction in the number of transfer passages from 22 to 11 holes of $\frac{3}{32}$-inch diameter resulted in a marked increase in leakage above the fuel-flow rate of 1000 pounds per hour.

Fuel-discharge restrictive orifices. - A series of tests were run to investigate operating characteristics of a unit designed to increase the dispersion and atomization of the impeller discharge streams. This unit had restrictive orifices inserted in the radial-discharge passages at the points of fuel injection around the impeller periphery. Orifice sets of one $\frac{1}{16}$-inch-, eleven $\frac{1}{16}$-inch-, twenty-two $\frac{1}{32}$-inch-, eleven $\frac{1}{64}$-inch-, and twenty-two $\frac{1}{64}$-inch-diameter orifices were used in the same installations. Results of these tests showed a considerable increase in leakage for the reduced-size orifices. The restriction of the air flow through the impeller passages caused by the reduction in orifice area reduced the rotational suction effect through the collector cup and thus increased the magnitude of the leakage. The total orifice area, and to a larger extent, the area per orifice determined the maximum flow that could be attained before the leakage became excessive. Of the five sets of orifices tested, the impellers with 11 orifices $\frac{1}{16}$ inch in diameter and 22 orifices $\frac{1}{32}$ inch in diameter were found to have satisfactory leakage rate of less than 5 percent over the normal engine operating range.

Peripheral symmetry of distribution. - No appreciable difference in distribution due to either impeller or collector-cup design modifications was noted for any of the tests in which there were 11 or 22 impeller discharge orifices, regardless of the size of the restriction. It was found, however, that the symmetry of distribution was affected by nozzle-ring performance. The variation in distribution symmetry in these tests was due to the ineffectiveness of the impeller fuel-distribution annulus and the collector cup as equalizing chambers in eliminating maldistribution of flow originating at the nozzle ring. On the basis of these distribution tests, it was concluded that, for a hydraulic system similar to that of the injection impeller designed for the engine, symmetry of peripheral distribution was principally a function of the distribution established at the nozzle-ring discharge.

Nozzle-ring flow pattern. - Several distribution and bench-flow tests were conducted to investigate the correlation between the flow distribution established at the nozzle-ring discharge and that obtained at the impeller periphery. Constant-speed distribution trends over a range of fuel flows (fig. 4(b), for example) indicated large uniformity deviations at low flows with a gradually improving discharge symmetry with increasing fuel rates. This same result was observed in bench-flow tests of nozzle-ring flow patterns, which revealed a marked variation in the uniformity of the discharge at low rates of flow. The nozzle-ring flow variation gradually improved with increasing rates of flow until all holes were flowing uniformly full. Furthermore, the flow range at which all the discharge orifices in the nozzle ring began to flow full was marked in the distribution tests by a corresponding improvement in impeller-discharge symmetry with a fairly consistent pattern maintained above that flow.

In order to check further the effectiveness of the impeller-collector cup unit in equalizing any asymmetry of flow originating at the nozzle ring, a set of tests was run on an installation in which a marked nonuniformity of flow was created at the ring by alternately plugging a series of discharge orifices in various sectors of the nozzle ring. Results of this investigation revealed a very definite increase in the deviation from average impeller distribution over the original open-discharge condition. The uniform spacing of a large number of discharge orifices of minimum area is therefore desirable for insuring a uniform nozzle-ring flow pattern and symmetrical impeller discharge.

Distribution through impeller. - A fluid dye was passed through the original impeller unit for the engine to indicate the flow pattern through the impeller and collector cup. The fluid ran directly from the collector cup and fuel-transfer passage to the corresponding radial discharge passage; thus the distribution established at the exit of the collector cup was carried through to the impeller discharge without any equalization in the impeller annulus. The entrance to the radial discharge passages in this unit provided insufficient restriction to cause fuel mixing or build-up at this point.

The equalizing effect of fuel mixing in the impeller fuel-distribution annulus was indicated by a test of the original unit in which only one radial discharge passage was left open. Distribution results revealed good characteristics with a definite improvement at low flows. A form of annulus restriction at the entrance to the discharge passages that would cause a common annular build-up of fluid without restricting the air flow is therefore desirable.

The fuel-equalizing tendencies of the unit might also be improved by providing adequate fluid rotation in the collector cup and by providing a chamber in which the centrifugal forces of rotation equalize the fluid around the circumference of the cup. The collector-cup length and space available in the unit designed for the engine were insufficient to realize these principles completely.

System with progressive metering to fuel-discharge passages. - As part of the impeller peripheral-distribution investigation, a further alteration was made in the impeller-annulus and radial-discharge passage entrances to provide a more pronounced equalizing-chamber distributing effect. The purpose of this design was to maintain a common fuel reservoir in the annulus over the full engine operating range by progressively restricting or metering the flow. This fuel build-up was accomplished by the insertion of metering plugs with delivery orifices of varying areas into counterbored recesses in the radial-discharge passage entrances, as shown in figure 6. This design was based on the theory that a common fuel build-up under the action of centrifugal force would exert an equal discharge pressure on all delivery orifices, thus tending to equalize any previous asymmetry of flow and to promote a uniform peripheral distribution. Air passages were provided in the plug stems to eliminate any restriction to the air flow and thereby maintain minimum transfer leakage.

Test results of this design indicated that peripheral distribution can be improved by a form of flow restriction and common fuel build-up. A set of tests run under build-up conditions (the existence of fuel build-up was verified by dye patterns) revealed a marked improvement in the symmetry of the distribution. Maximum chamber deviations from perfect distribution were reduced over the no build-up condition from an average value of 7.30 to 3.21 percent over the test range of engine operation and an improvement was realized over the distribution found in the test of the original unit designed for the engine (4.70-percent average maximum deviation).

It was found, however, that the size. the number, and the orientation of the discharge orifices were critical design factors. For the given depth of build-up, a change in the orifice size and location tended to shift the range in which best results were realized. Because the build-up is a function of both flow rate and engine speed, optimum design conditions would require a build-up depth range sufficient to maintain the pressure effect over the complete engine operating range. Further investigation indicated that the discharge area required for this increased build-up depth would be so small that only a limited number of discharge orifices would be permitted. In this case, difficulties might arise due to the centrifugal separating action of the impeller in depositing the sludge and impurities in the fuel and to the orifice-plugging tendencies of these impurities.

CHARACTERISTICS OF DIRECT-FLOW IMPELLER

Results of the leakage test conducted on the unit in which fuel was introduced directly into the fuel-distribution annulus of the impeller are shown in figure 7. The principal characteristic of these leakage results was the almost complete dependence of leakage on the rate of fuel flow for the greater portion of the test-flow range. Because fuel was delivered directly into the impeller annulus, the possible effects of the pumping action of a fuel-transfer unit were absent. Comparison of leakage results in the direct-injection (fig. 7) and the original-design (fig. 3) installations showed the effect of a transfer unit possessing insufficient pumping action.

Transfer leakage in the direct-flow-impeller installation was primarily a function of nozzle-ring flow characteristics. The general effects of nozzle-ring flow variations on leakage were similar to those described for the original nozzle ring designed for the double-row radial engine unit. In the direct-flow unit, gravitation and insufficient flow caused direct dripping down the ring face and adhesion of the streams to the ring surface in the low-flow range of leakage.

At flows greater than the minimum leakage values where ring discharge jets were flowing clear, the gradual rise in leakage was due to an increase in nozzle-ring jet divergence, splashing, and dripping. As only one of this type of unit was tested, however, the complete leakage variations with fuel flow and engine speed were not explored. The leakage results of the direct-flow unit over the test range of engine operation are generally similar to those of the original design unit for the engine, and therefore the use of this simplified design having minimum space requirements for any engine installation in which it can be used would be satisfactory.

SUMMARY OF RESULTS

Mock-up tests of the NACA injection impeller designed for an 18-cylinder double-row radial air-cooled engine indicated that the unit had the following hydraulic characteristics:

1. Fuel-transfer leakage characteristics were satisfactory, with a leakage of less than 5 percent over the normal operating range. Even this small amount of leakage was distributed with a reasonable degree of uniformity into the impeller entrance as a fine spray sheet.

2. Peripheral fuel distribution was adequately uniform over the normal operating range with a maximum deviation of less than 5 percent. Distribution improved with increasing flow but even at starting flows the degree of uniformity was satisfactory.

From test investigations of component design alterations of the mock-up injection-impeller unit, the following characteristics and results were obtained:

1. The combination of 11 orifices $\frac{1}{16}$ inch in diameter and 22 orifices $\frac{1}{32}$ inch in diameter in the original design unit produced a satisfactory leakage characteristic of less than 5 percent over the normal engine operating range. Excessive leakage rates were found with orifice sets of 11 and 22 orifices $\frac{1}{64}$ inch in diameter.

2. Maximum fuel-pumping action in the collector cup was found desirable for best leakage characteristics. Improved pumping action was obtained with a collector cup embodying an increase in the number and height of the fuel-induction vanes.

3. Maximum nozzle-ring discharge-jet velocity consistent with fuel-pressure limitations and a uniform spacing of a large number of discharge orifices of minimum area were found desirable for minimum leakage rates and for a uniform nozzle-ring flow pattern.

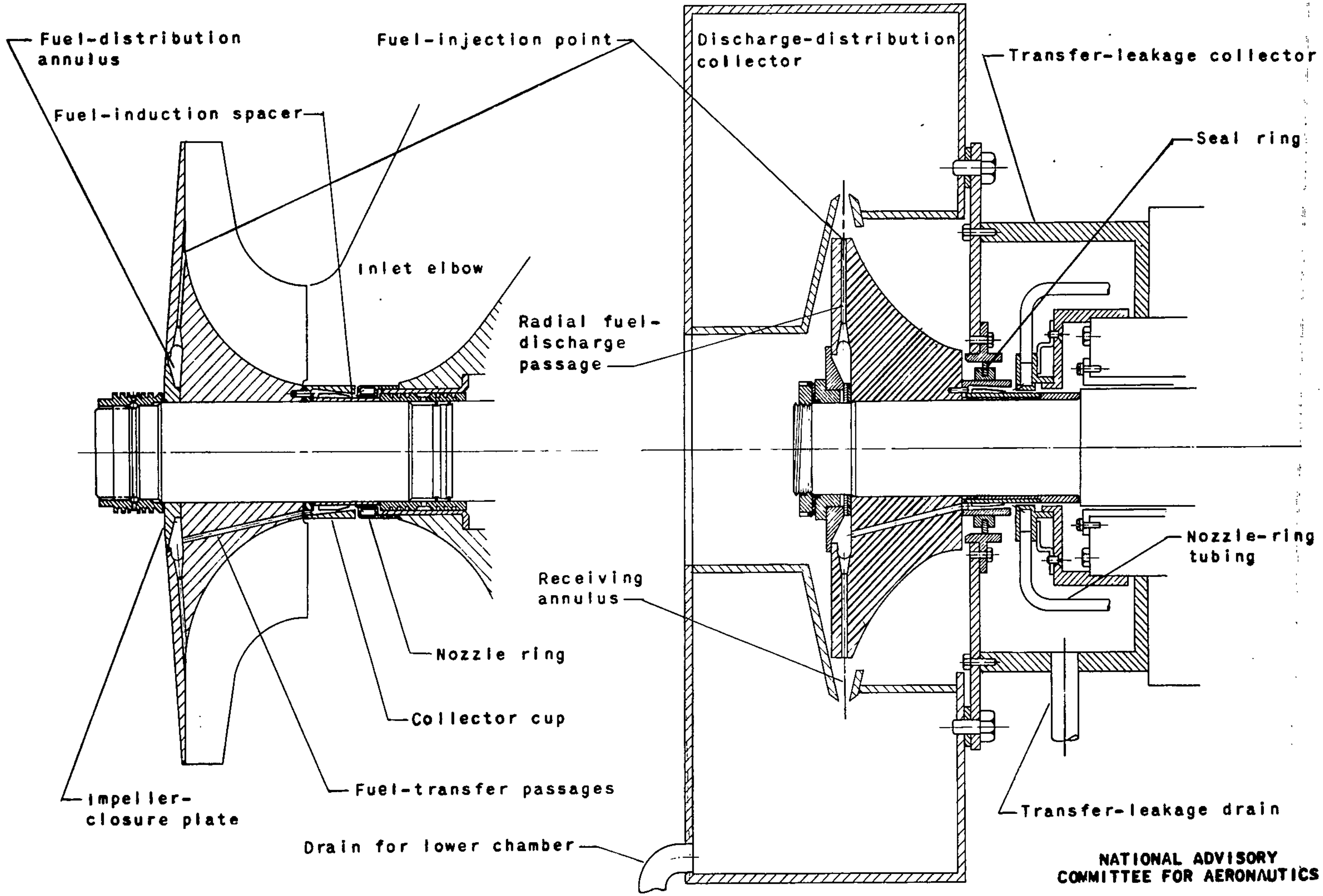
4. Symmetry of peripheral distribution was generally satisfactory for all operational design variations. A form of common fuel build-up in the impeller was found effective in improving distribution symmetry results.

5. Transfer leakage for the single design unit in which fuel was delivered directly into the distribution annulus of the impeller was found to be less than 5 percent in the range of engine operation at fuel flows from about 1000 to 2400 pounds per hour.

National Advisory Committee for Aeronautics,
Aircraft Engine Research Laboratory,
Cleveland, Ohio.

REFERENCE

1. Supercharger and Airflow Research Division: Effect of the NACA Injection Impeller on the Mixture Distribution of the Wright R-3350 Engine. NACA MR No. E4L23a, Army Air Forces, 1944. (Available as NACA TN No. 1069, 1946.)



(a) Original installation for double-row radial engine.

(b) Original mock-up impeller test installation.

Figure 1. - NACA injection impeller.

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

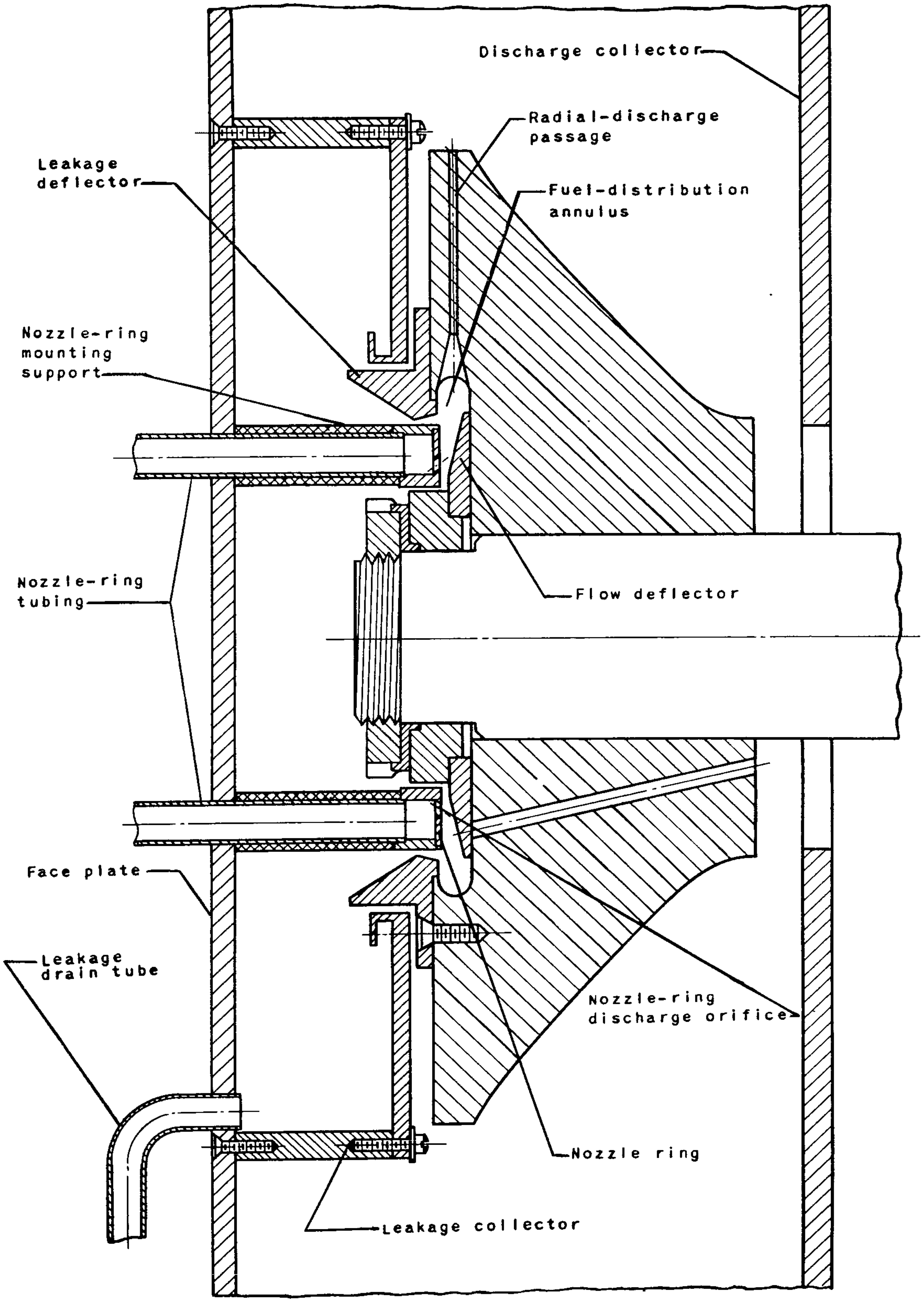


Figure 2. - Direct-flow injection-impeller installation.

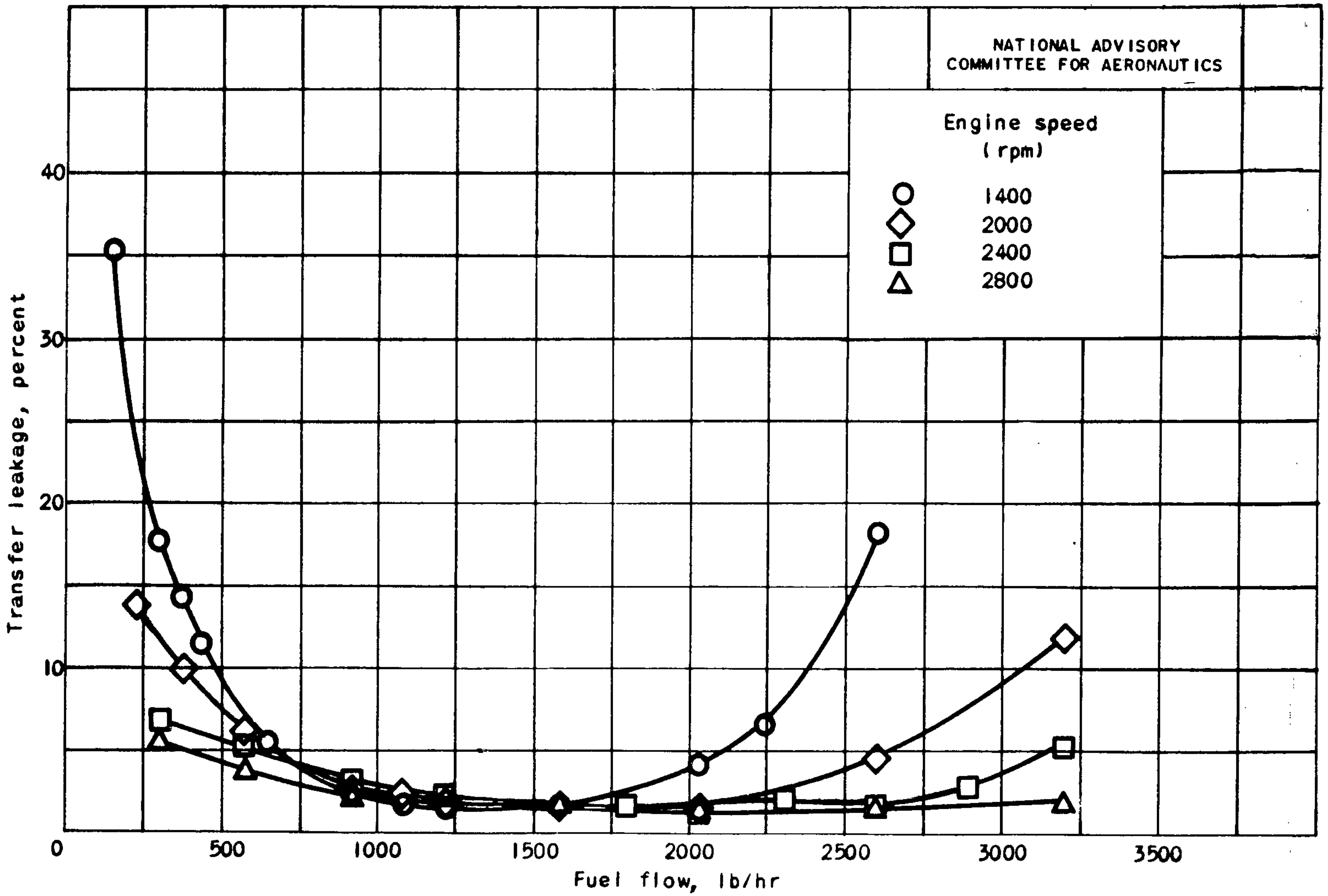
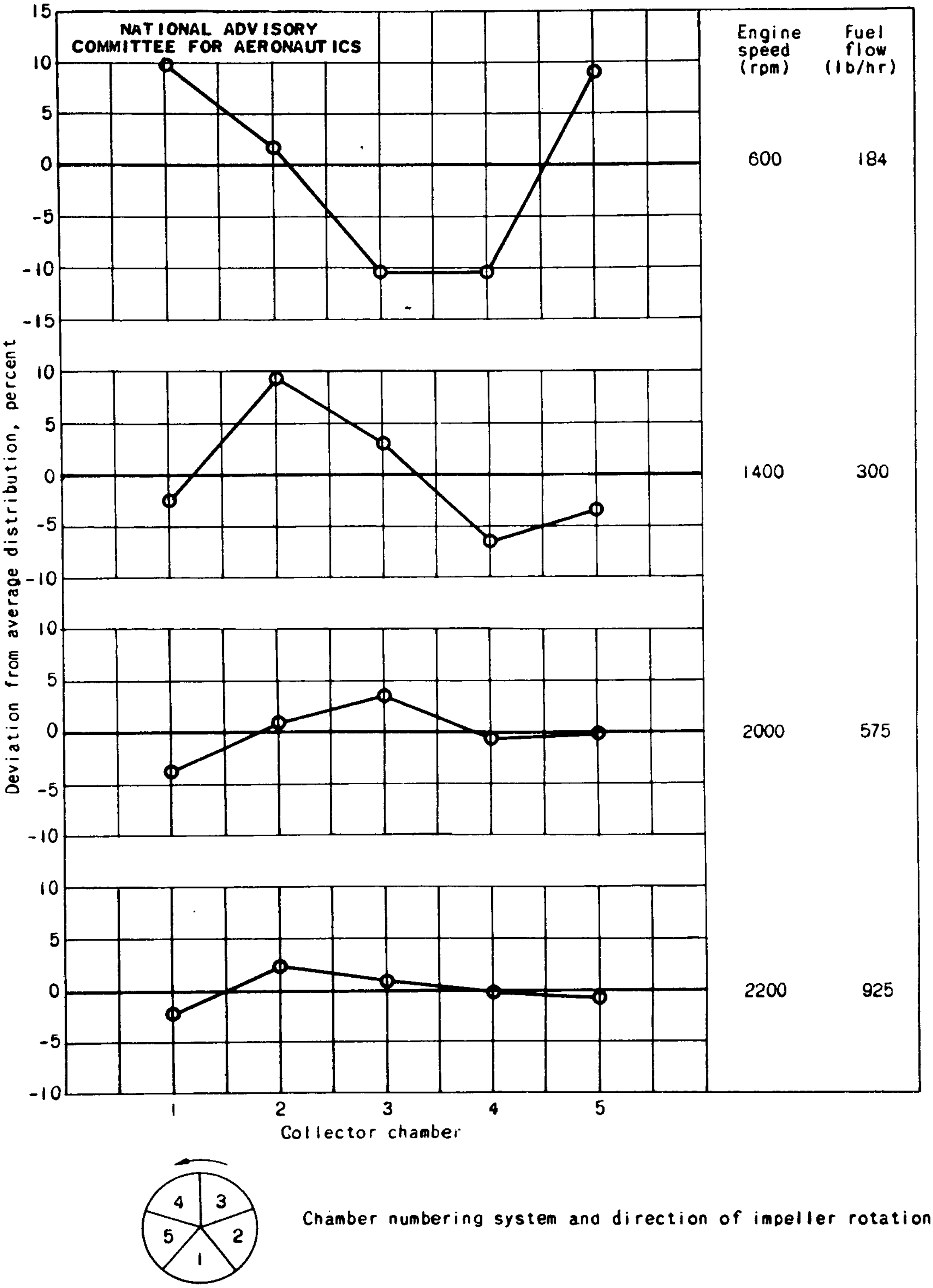
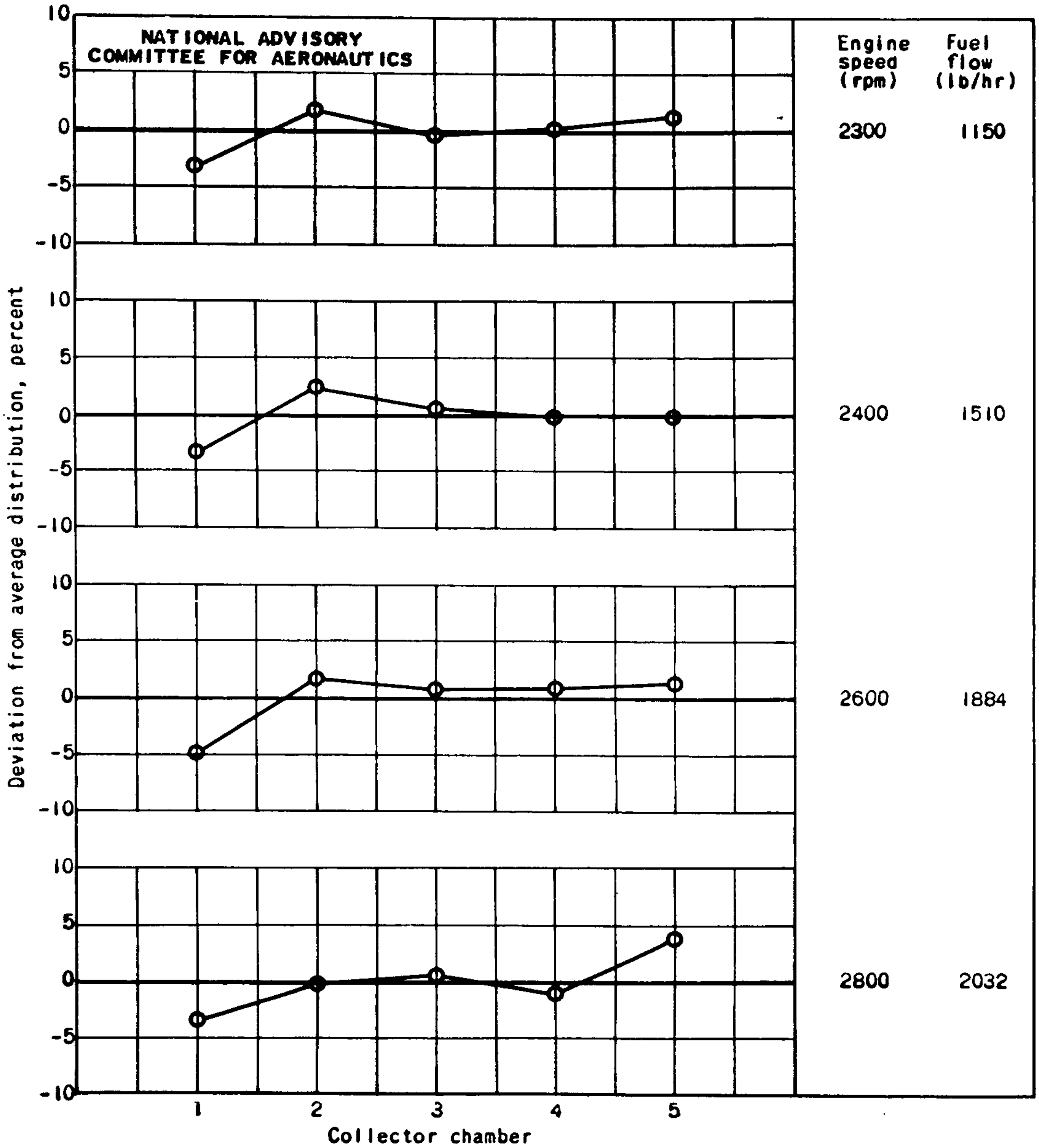


Figure 3. - Leakage in fuel-transfer unit in original injection-impeller installation for double-row radial engine.



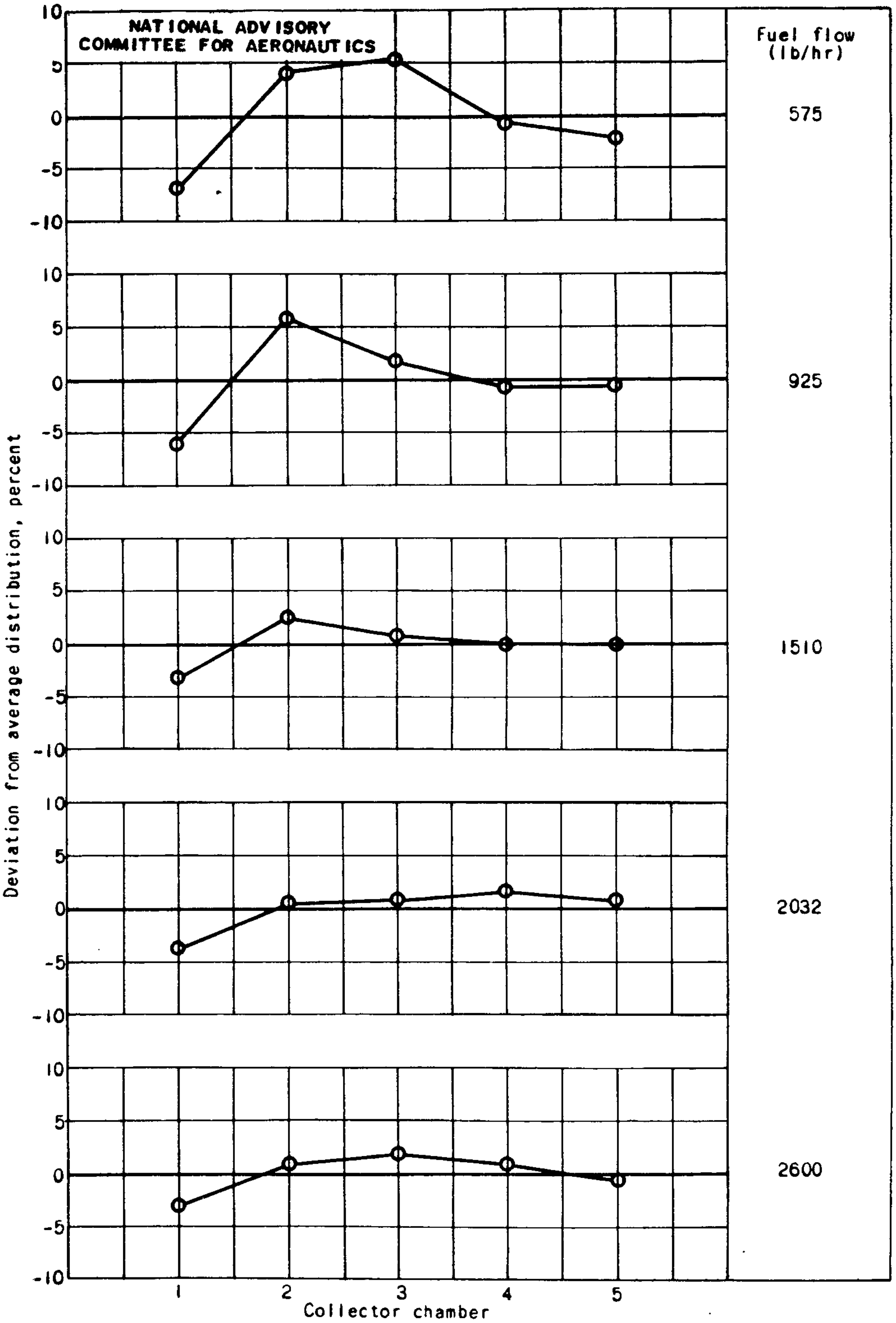
(a) Test range of engine operation.

Figure 4. - Peripheral fuel distribution in original injection impeller for double-row radial engine.



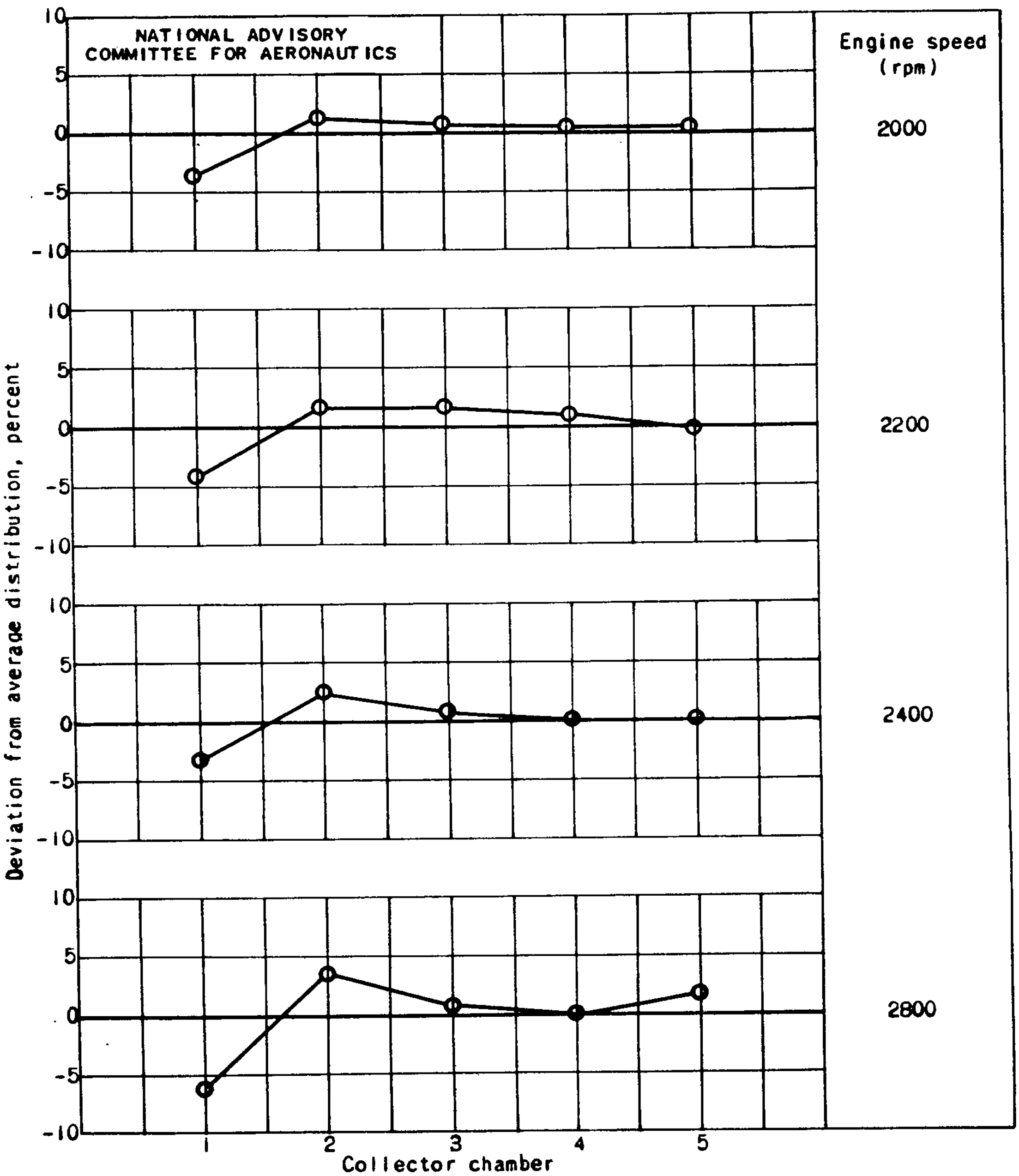
(a) Test range of engine operation. - Concluded.

Figure 4. - Continued.



(b) Fuel flows at engine speed of 2400 rpm.

Figure 4. - Continued.



(c) Engine speeds at fuel flow of 1510 pounds per hour.

Figure 4. - Concluded.

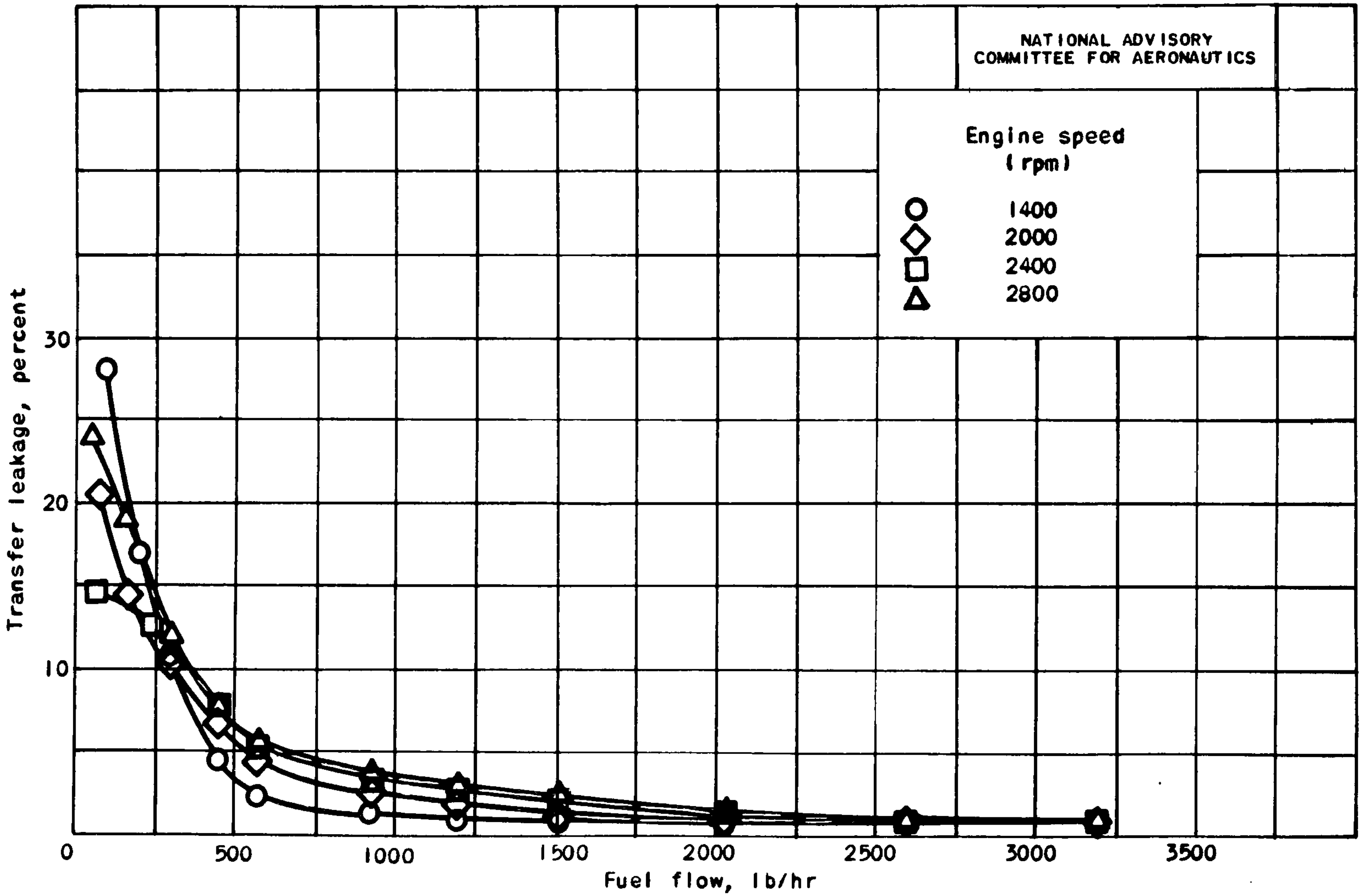


Figure 5. - Leakage in fuel-transfer unit in original injection-impeller installation for double-row radial engine with revised collector-cup nozzle-ring unit having increased pumping action.

NACA MR No. E6C25

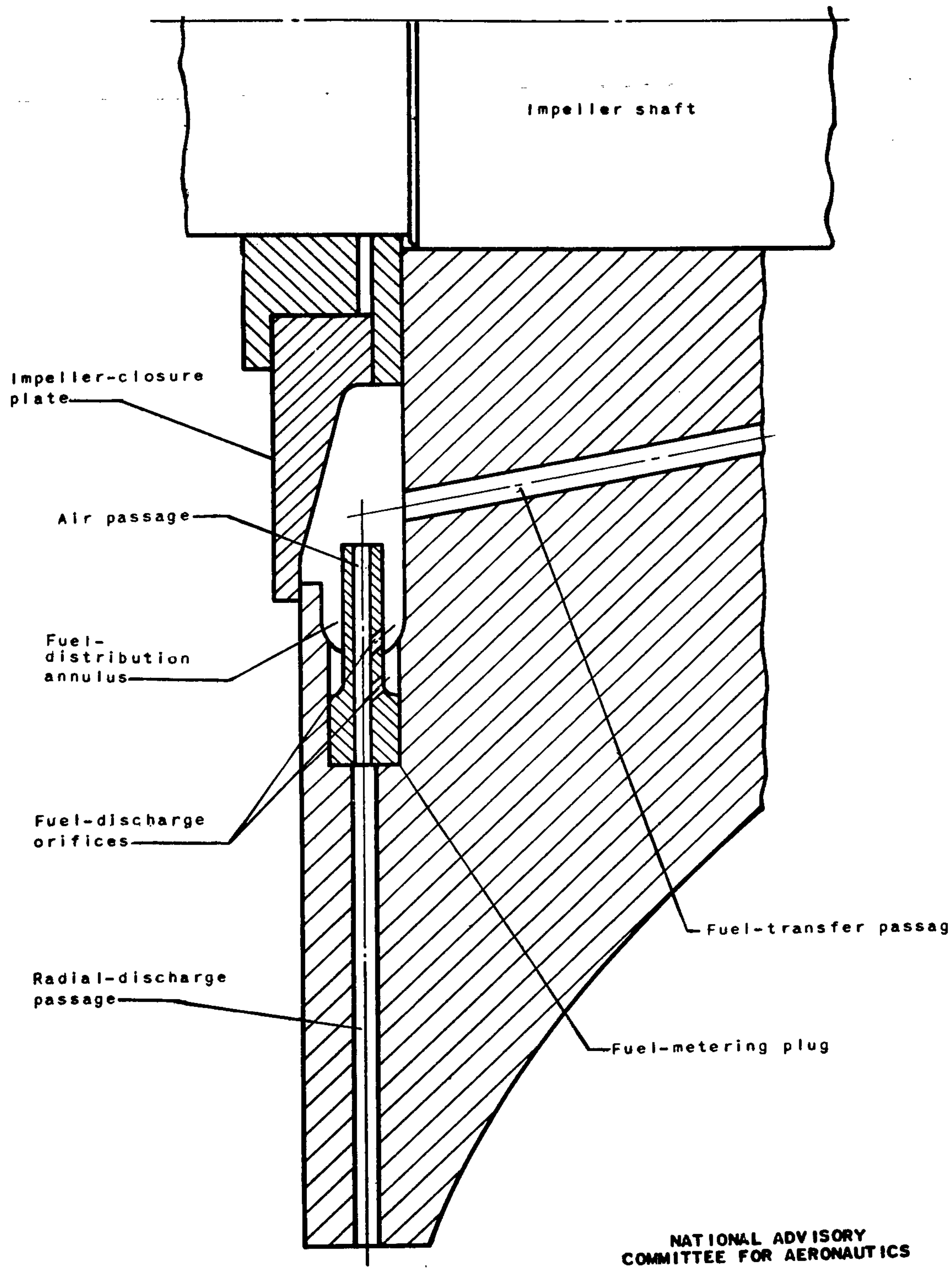


Figure 6. - Installation of plugs for progressive fuel metering in original injection-impeller installation for double-row radial engine.

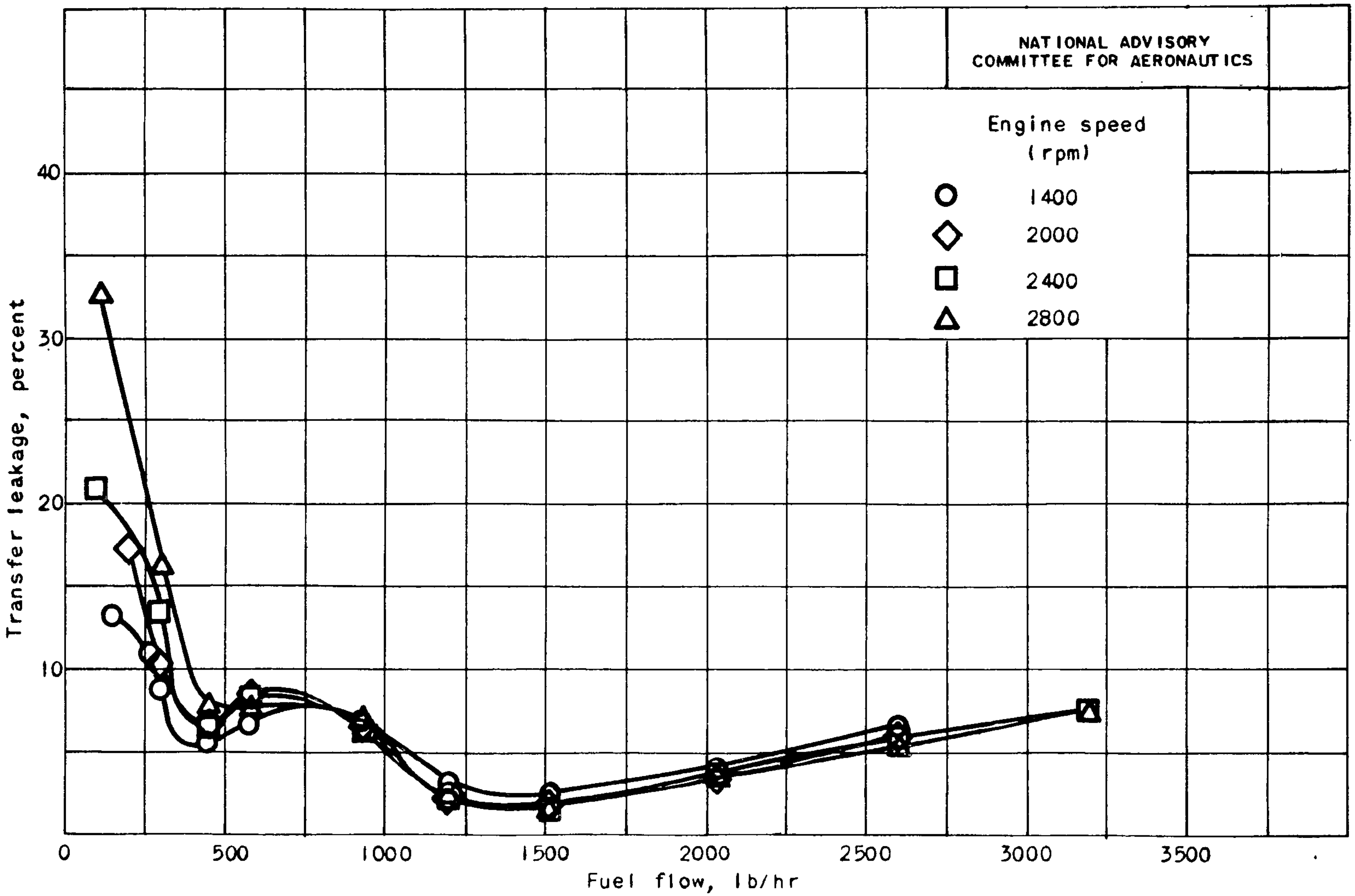


Figure 7. - Transfer leakage in installation in which fuel was directly delivered into annulus of original injection impeller for double-row radial engine.